BIOMORPHIC EXPLORERS LEADING TOWARDS A ROBOTIC ECOLOGY

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DARPA/ISAT STUDY MEETING: TOWARDS A ROBOTIC ECOLOGY
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BIOMORPHIC EXPLORERS

- COOPERATIVE BEHAVIORS OF VERSATILE MOBILE ENTITIES
  - INTERDEPENDENCE
  - EFFICIENT USE OF NATURAL AND EXISTING RESOURCES
- TO PROVIDE EXTENDED SURVIVAL AND USEFUL LIFE OF THE ROBOTS TOWARDS FULFILLMENT OF THE MISSION/APPLICATION

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BIOMORPHIC EXPLORERS

- SMALL, DEDICATED, LOW-COST EXPLORERS THAT CAPTURE SOME OF THE KEY FEATURES OF BIOLOGICAL EXPLORERS
  - VERSATILE MOBILITY: aerial, surface, subsurface, and in fluids
  - ADAPTIVE, DISTRIBUTED OPERATION
  - BIOMORPHIC COOPERATIVE BEHAVIOR
- CONDUCTED WORKSHOP, AUG 19-20, 1998
  - SPONSORED BY NASA/JPL
  - VERY SUCCESSFUL; OVER 150 PARTICIPANTS

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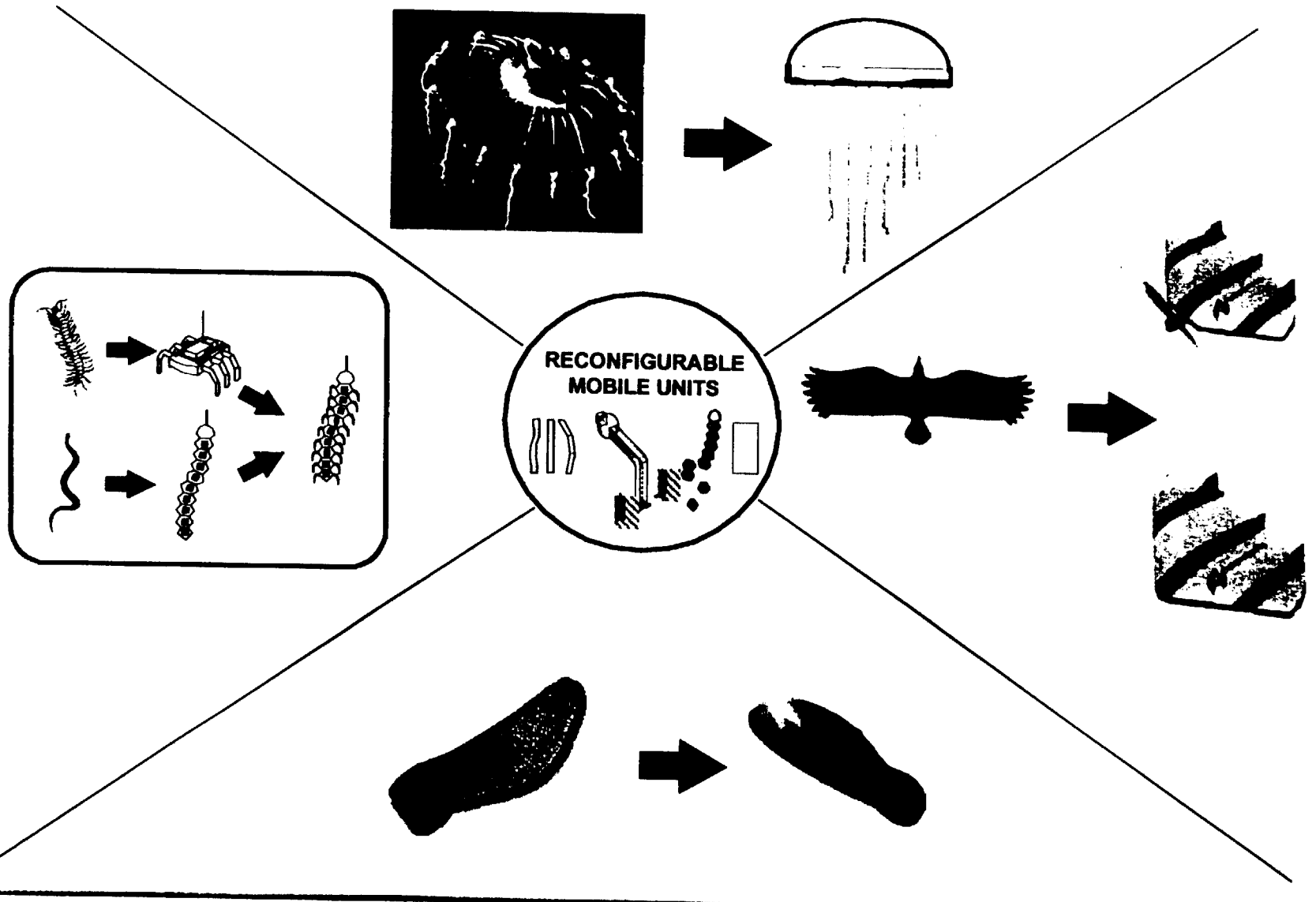
ADVANCED MOBILITY FOR BIOMORPHIC EXPLORERS



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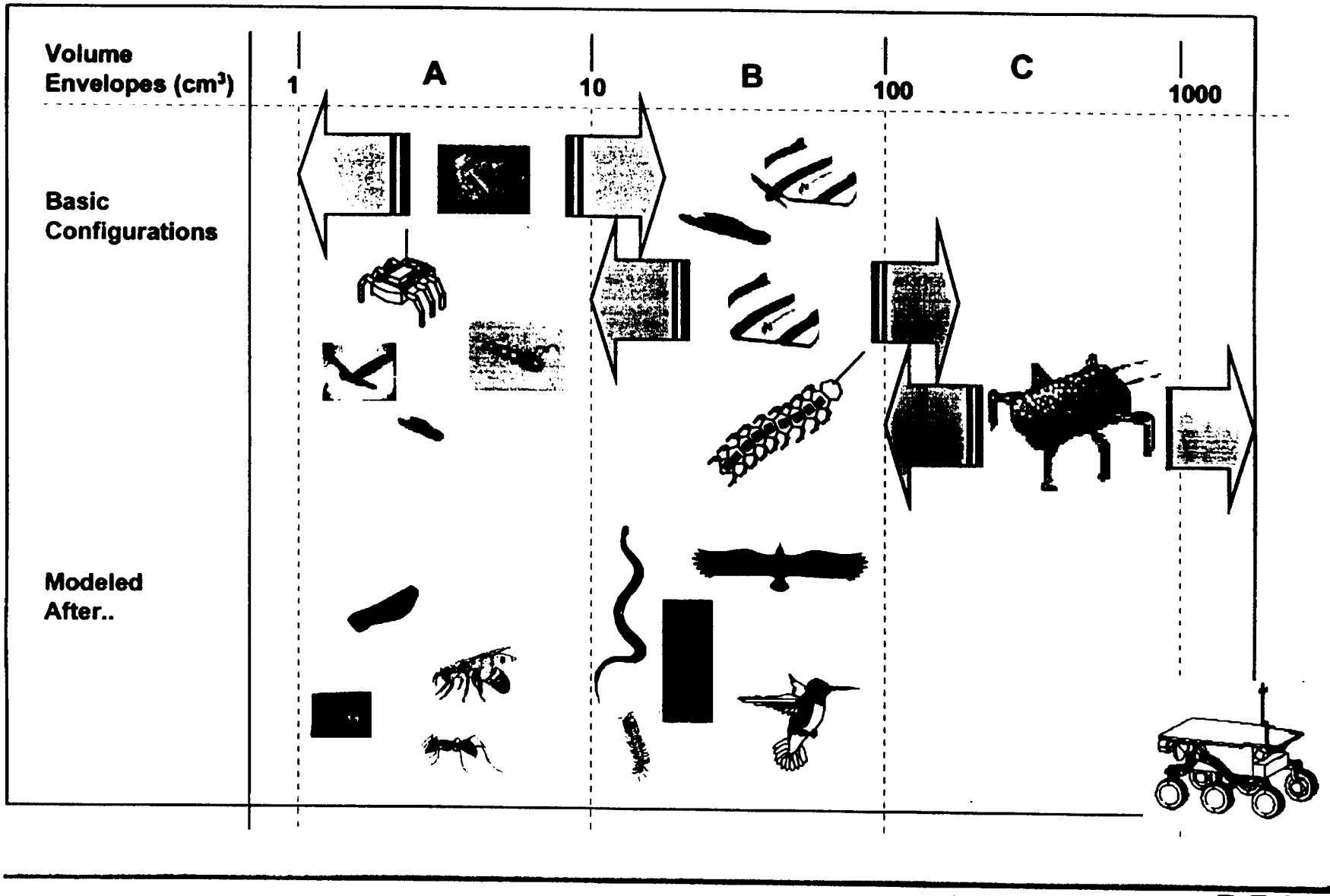
BIOMORPHIC EXPLORERS: SIZE BASED CLASSIFICATION



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Biomorphic Explorers: Classification (Based on Mobility and Ambient Environment)

Biomorphic Explorers

Aerial

Surface/Subsurface

Biomorphic Surface Systems

Biomorphic Subsurface


Seed Wing


Honey Bee


Ant


Centipede

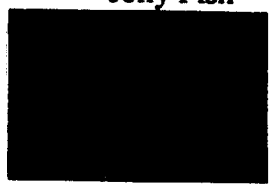

Jelly Fish


Soaring Bird


Humming Bird


Snake


Earthworm


Germinating Seed

Examples of biological systems that serve as inspiration for designing the biomorphic explorers in each class

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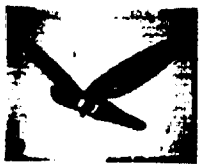
Biomorphic Explorers: Classification (Based on Mobility and Ambient Environment)

Biomorphic Explorers

Aerial

Seed Wing Flyer (60 g)



Ornithopter

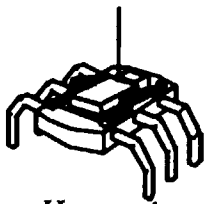
Glider (75 g)

Powered Flyer

Surface/Subsurface

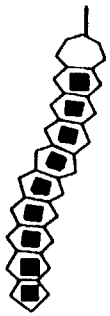
Biomorphic Surface Systems

Biomorphic Subsurface



Hexapod (1-2 kg)

Reconfigurable Legs/Feet



Artificial Jelly Fish

Artificial Earthworm

Worm Robot (85 g)

Candidate biomorphic explorers on the drawing board, with mass of design under study in 1998 in parentheses

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Biomorphic Flight Systems: Vision

- Extended reach over all kinds of terrain
- Unique perspective for imaging and Spectral Signature
- Many flyers work in cooperation with larger aircraft, and balloons to enable new missions to reach currently inaccessible locations

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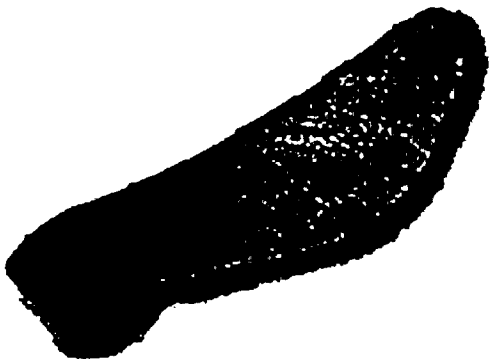
BIOMORPHIC FLIGHT SYSTEMS



a. Seed Wing Pod

TOTAL MASS: 57 g →
PAYLOAD MASS: 48 g

b. Seed Wing Pod Flyer

← TOTAL MASS: 57 g
PAYLOAD MASS: 32 g

c. Biomorphic Glider

TOTAL MASS: 57 g →
PAYLOAD MASS: 6 g

d. Biomorphic Flyer

Biomorphic flight systems offer rapid mobility and extended reach. For comparison the above illustrates for the same total mass of the system, the respective payload fractions in each case

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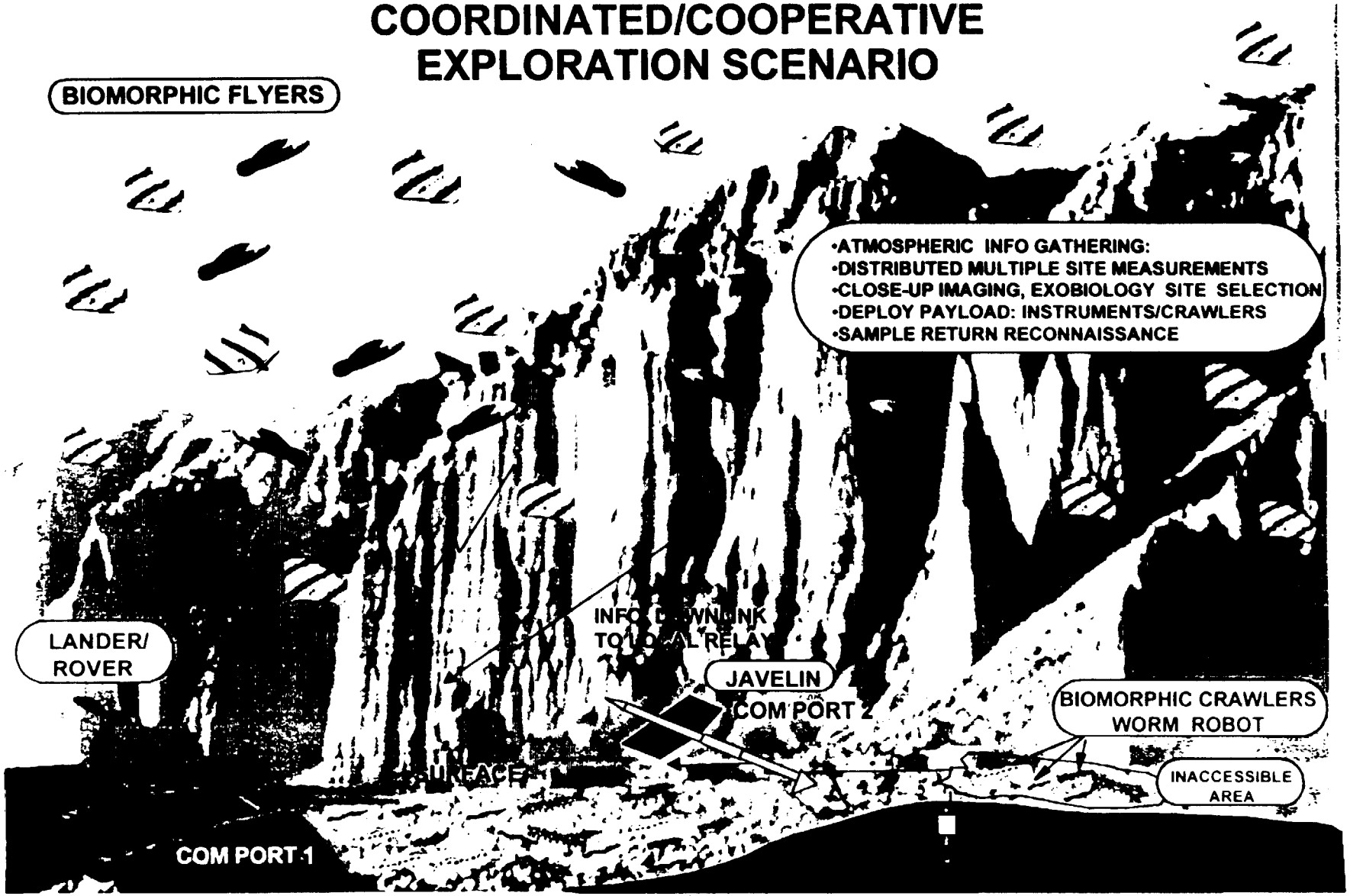
COORDINATED/COOPERATIVE EXPLORATION SCENARIO



COOPERATIVE ORGANIZATION OF LANDER, ROVER, AND A VARIETY OF INEXPENSIVE BIOMORPHIC EXPLORERS WOULD ALLOW COMPREHENSIVE EXPLORATION AT LOWER COST WITH BROADER COVERAGE.

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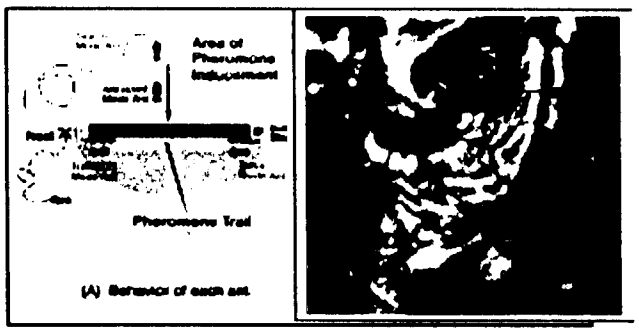
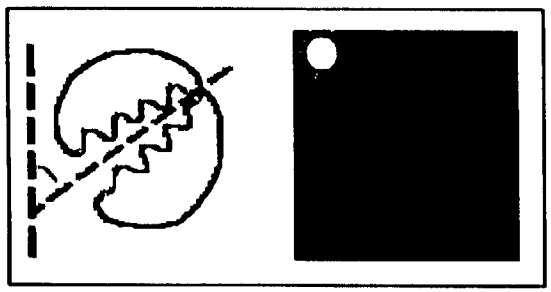
Insects operating cooperatively :



Nakamura and Kurumatani, 1995
Kubo, 1996

Ants' elaborate communication method with pheromone trails



Karl von Frisch, 1965
Wehner and Rossel, 1985
Barbara Shipman, 1997

Honeybee's recruitment dance with the sun as a celestial reference

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BIOMORPHIC EXPLORERS

- **PAYOFF**

- **BIOMORPHIC EXPLORERS, IN COOPERATION WITH CURRENT EXPLORATION PLATFORMS CAN ENABLE**
  - **EXPLORATION OF CURRENTLY INACCESSIBLE AND/OR HAZARDOUS LOCATIONS**
  - **MUCH BROADER COVERAGE OF EXPLORATION SITES**
  - **EXPLORATION AT LOWER COST**

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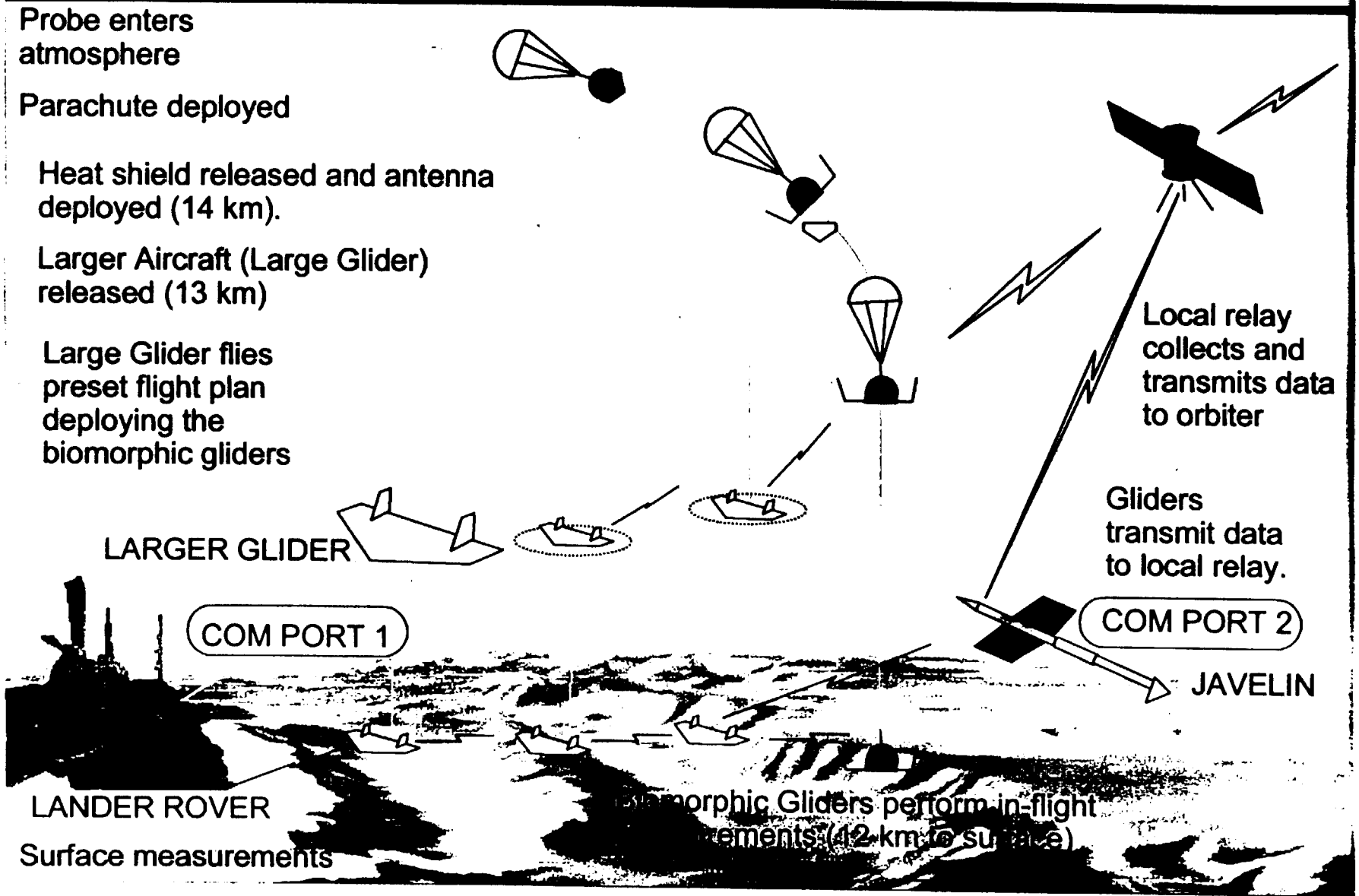
Biomorphic Glider Deployment Concept: Larger Glider Deploy/Local Relay



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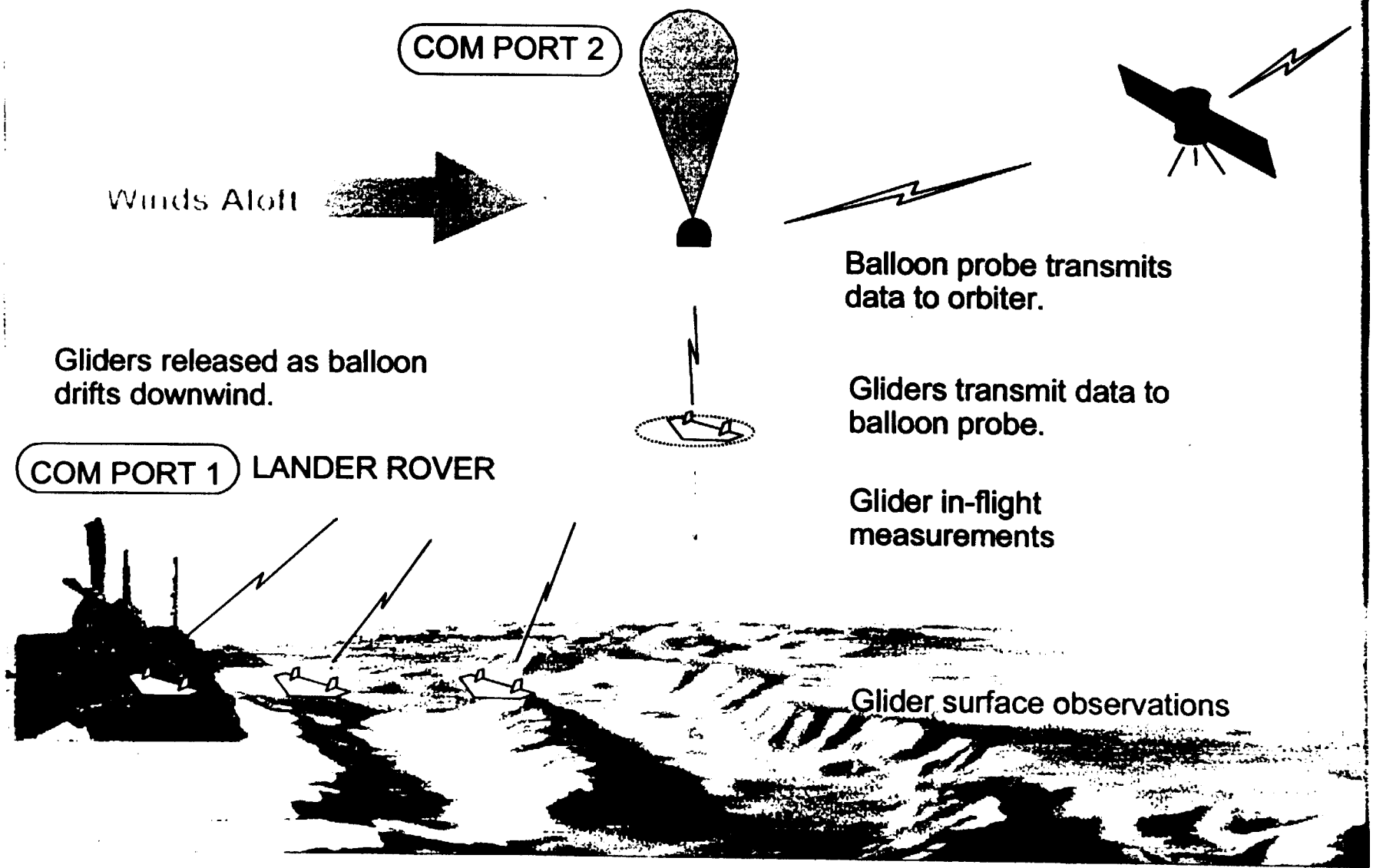
Biomorphic Glider Deployment Concept: Balloon Deploy/Dual Relay



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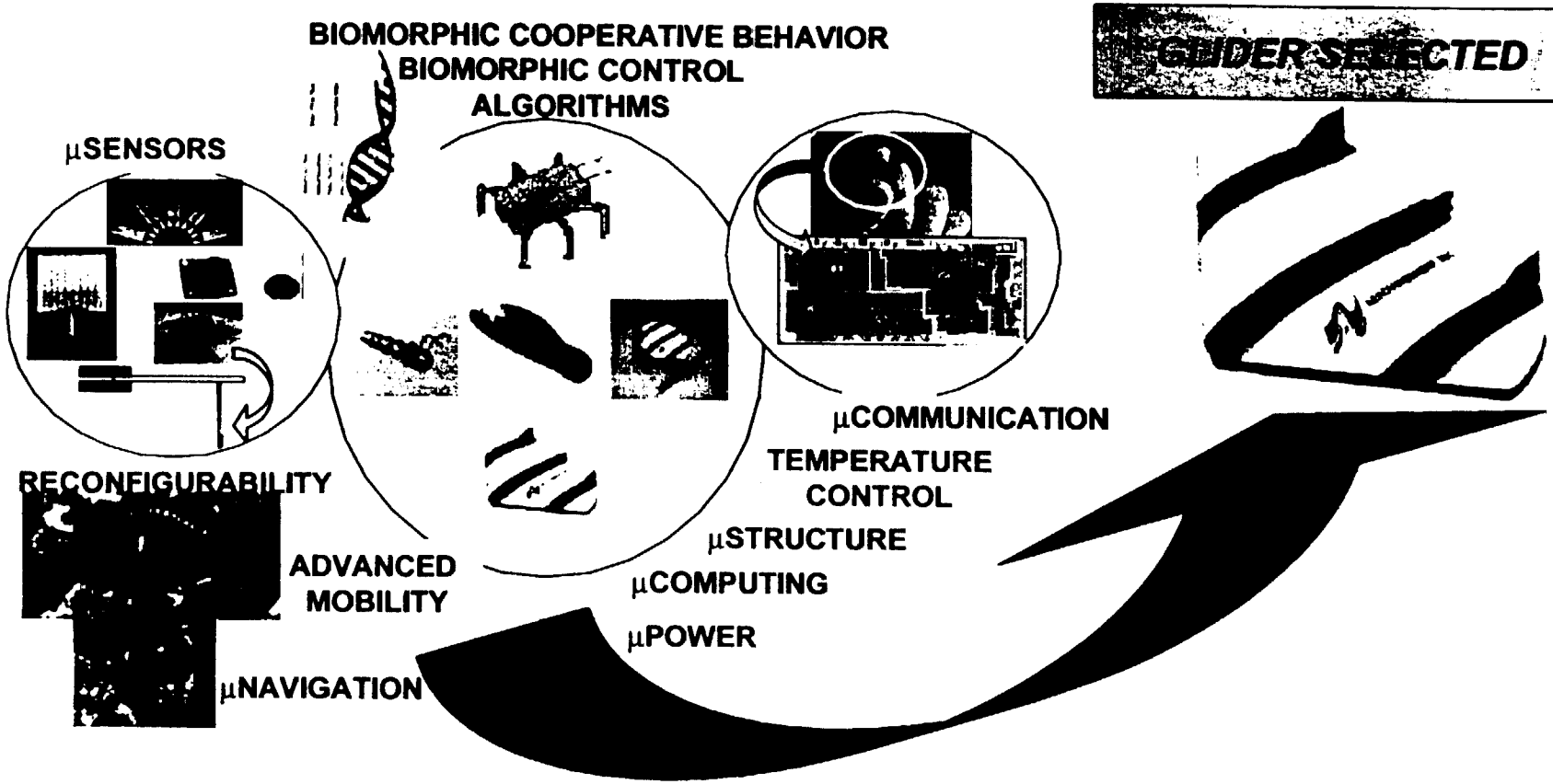
Biomorphic Explorer: Conceptual Design



SELECTION CRITERIA

- LOW MASS/VOLUME
- HIGH PAYLOAD FRACTION
- LARGE RANGE OF MOBILITY
- ACTIVE CONTROL
- IMPLEMENTATION READINESS

GLIDER BASELINE DESIGN CHARACTERISTICS

- MASS: 75 g
- PAYLOAD FRACTION : 60 %
- GLIDE RATIO , L/D ~ 5.8
- LARGE RANGE OF AERIAL MOBILITY: ~ 50 km to 100 km
- LEVERAGE FROM MAV TECHNOLOGY
- VOLUME: 300 cm^3
- ACTIVE FLIGHT CONTROL
- SOLAR NAVIGATION
- SOARING FLIGHT IN RISING CURRENTS
- COOPERATIVE MISSION: 32 GLIDERS
- COVERAGE AREA: ~ 100 km x 100 km

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Biomorphic Gliders

- Small, simple, low-cost system ideal for distributed measurements, reconnaissance and wide-area dispersion of sensors and small experiments.
- Payload mass fraction 50% or higher.

- small mass (100 g - 500 g)
- low radar cross section
- larger numbers for given payload due to low mass
- amenable to cooperative behaviors
- missions use potential energy: deploy from existing craft at high altitude
- Captures features of soaring birds, utilizing rising currents in the environment
- *Adaptive Behavior*
- *Self Repair features*

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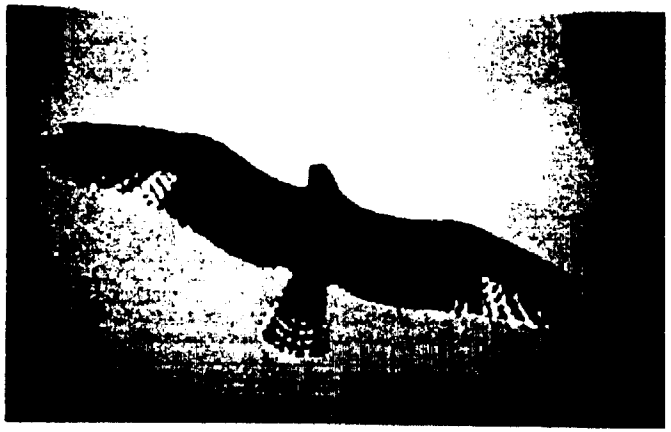
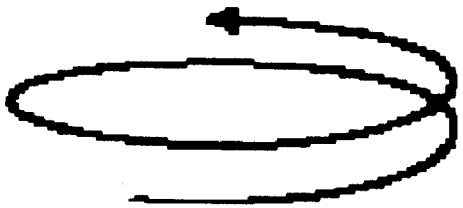
SOARING IN BIRDS





Vulture

For vultures and many other large birds, flying involves little effort. They hold their wings out and rise high into the sky by soaring — circling upward on columns of rising warm air called thermals. At the top of one thermal, they glide gently down in search of the next.

* Bird Photo by R.W. Scott and G. J. Scott

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Biomorphic Glider Deployment/Telecommunication Concept

Probe enters atmosphere

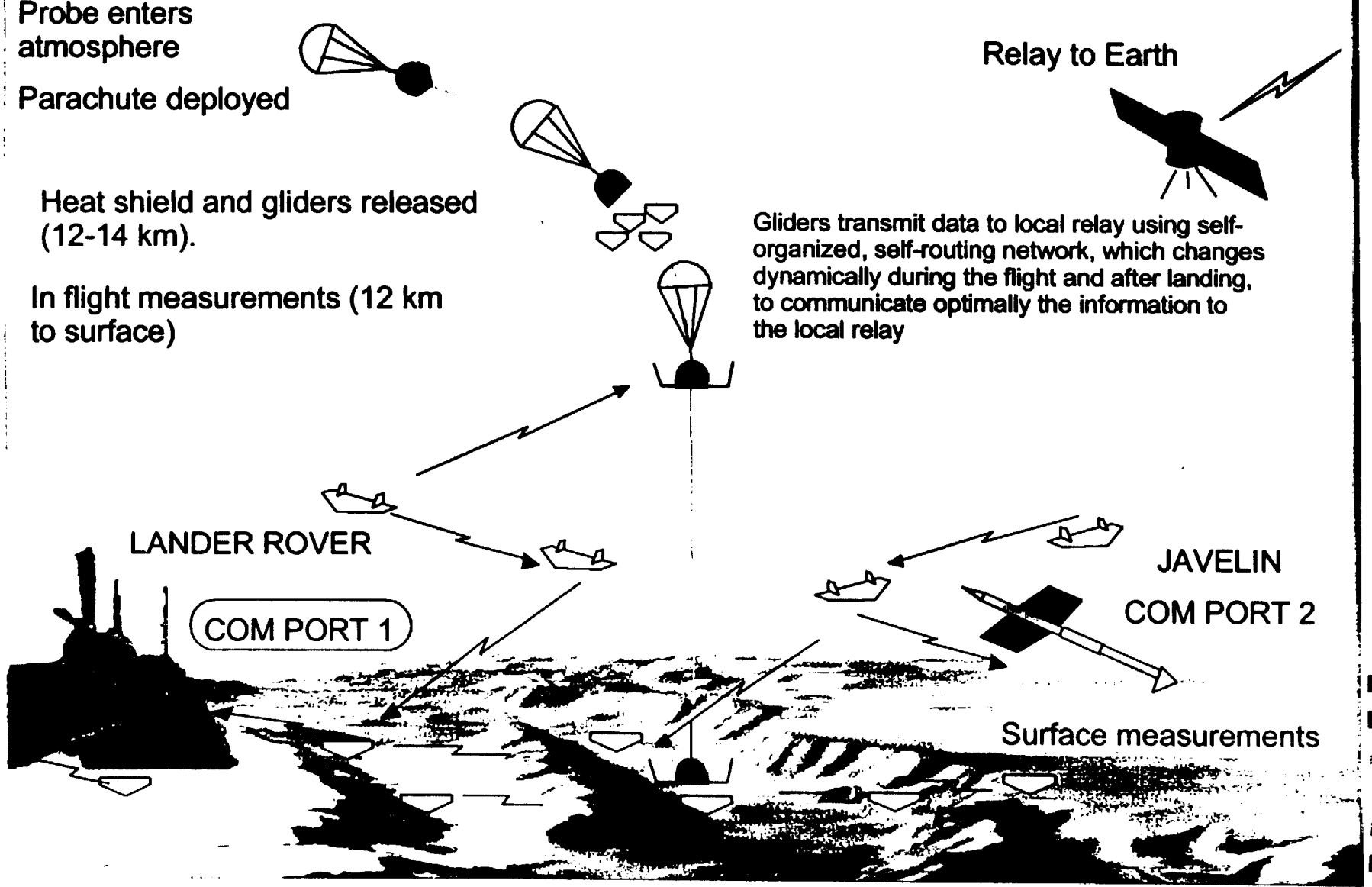
Parachute deployed

Heat shield and gliders released (12-14 km).

In flight measurements (12 km to surface)

Relay to Earth

Gliders transmit data to local relay using self-organized, self-routing network, which changes dynamically during the flight and after landing, to communicate optimally the information to the local relay



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Applications

- **Distributed Aerial Measurements**
  - **Ephemeral Phenomena**
  - **Extended Duration using Soaring**
- **Delivery and lateral distribution of Agents (sensors, surface/subsurface crawlers, clean-up agents**
- **Close-up Imaging, Site Selection**
  - **Meteorological Events: storm watch**
  - **Reconnaissance**
  - **Biological Chemical Warfare**
  - **Search and Rescue etc**
  - **Surveillance**
  - **Jamming**

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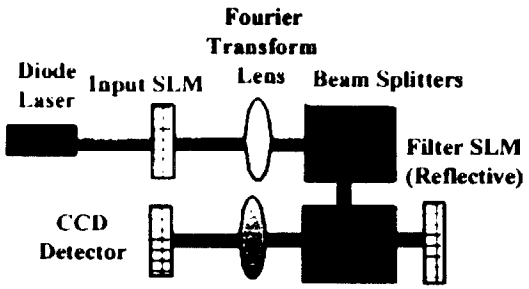
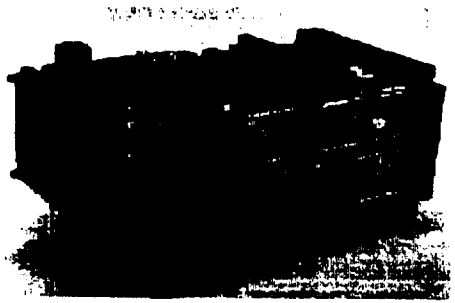
Demonstrated optical correlator can be miniaturized to fit in a small interceptor

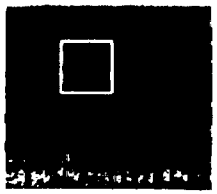
OPTICAL CORRELATOR SCHEMATIC



BMDO FUNDED CAMCORDER-SIZED GRAYSCALE OPTICAL CORRELATOR JPL - 1998



MATCH-BOX SIZED OPTICAL CORRELATOR TO BE DELIVERED FOR DOD AND NASA APPLICATIONS



Optical correlator provide wide-area search and track at the speed of light independent of sensor resolutions

Correlator output

JPL'S OPTICALCORRELATOR SETUP INSIDE THE VIGILANTE INSTRUMENT TRAILER DURING TEST AT MOJAVE (NOV. 1998)

VIGILANTE sensor platform and trailer

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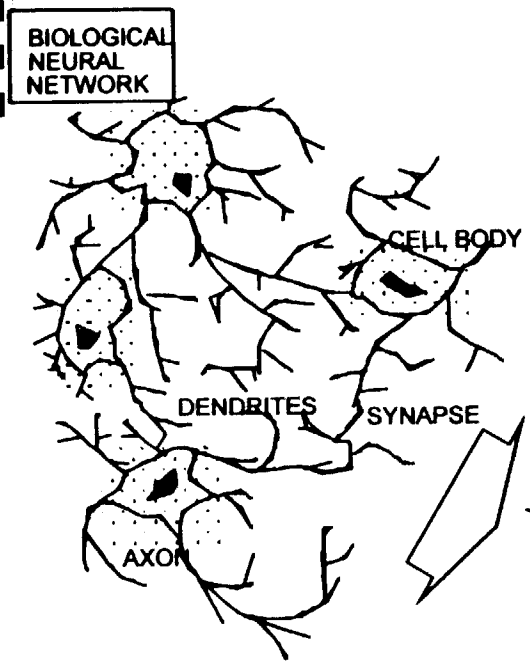
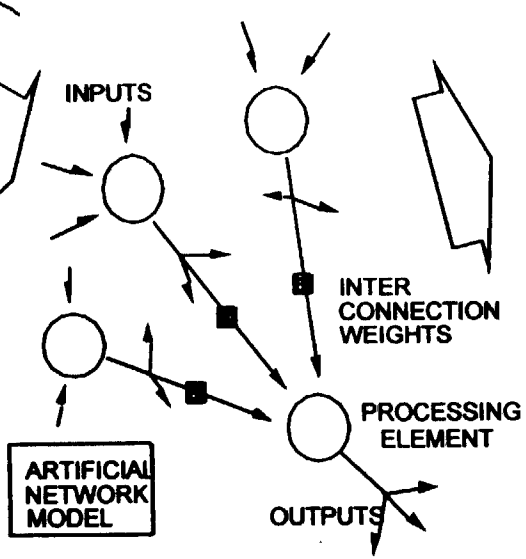
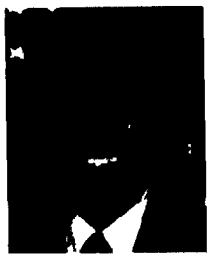
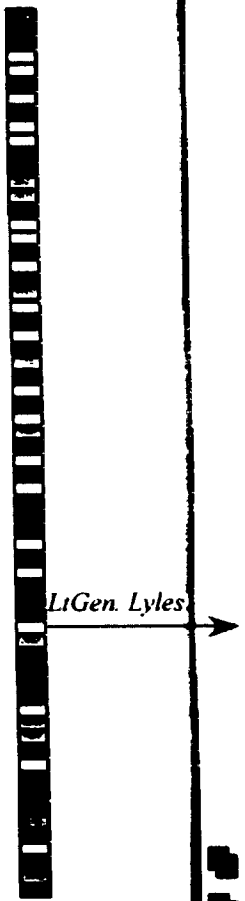
Background for 3-Dimensional Artificial Neural Network (3DANN)







10 gm, 5 cc, 2 W
On-chip IR detector
1 trillion 8-bit multiplies/sec
270 million template matches/sec
Compute power greater than fast supercomputer



3D neural network chip design enables the 3DANN technology that delivers unprecedented processing speed for ATR.

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SUMMARY & ROADMAP

Enabling better spatial coverage and access to hard-to-reach and hazardous areas at low recurring cost

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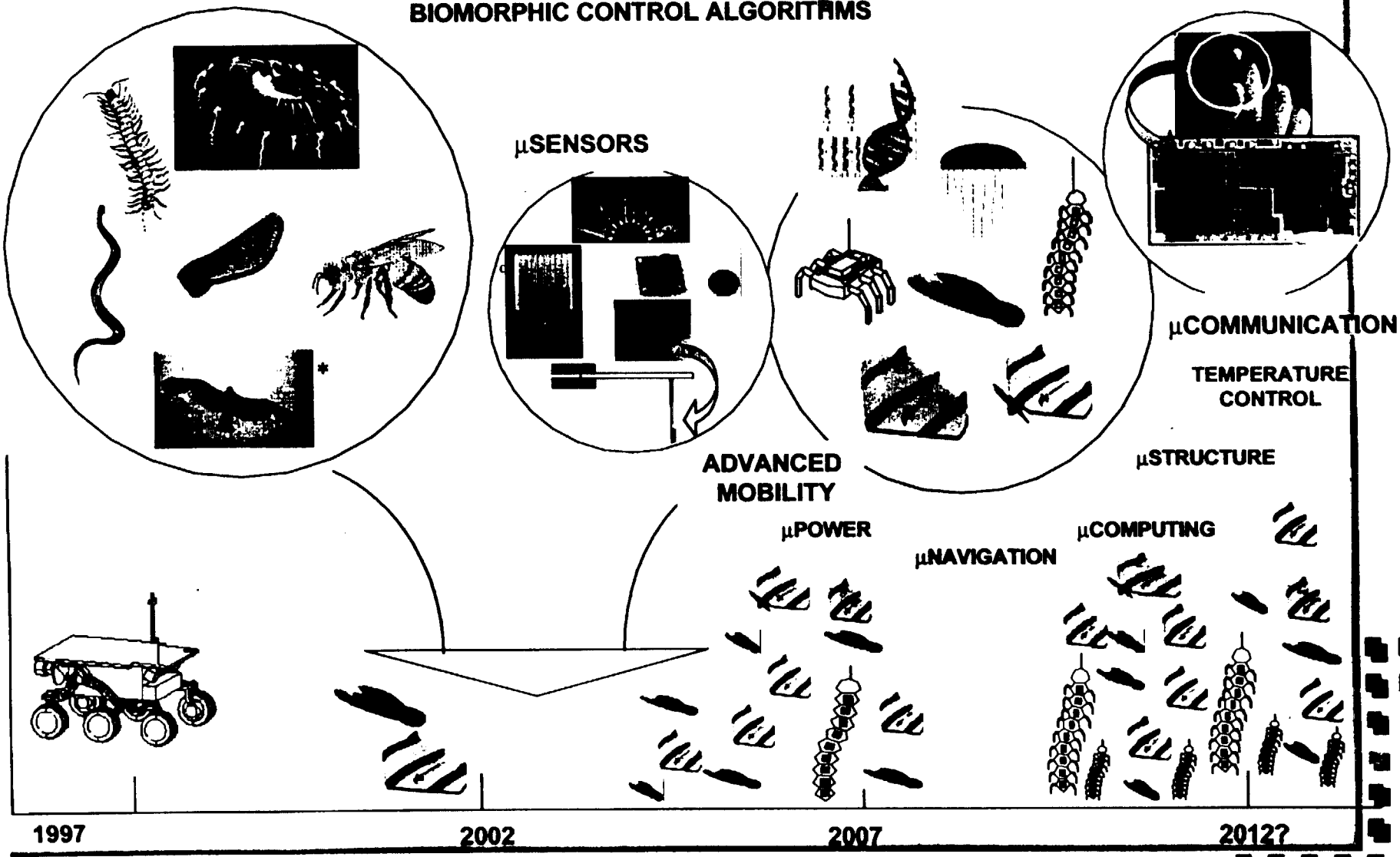
BIOMORPHIC COOPERATIVE BEHAVIOR
BIOMORPHIC CONTROL ALGORITHMS



* Bird Photo by R.W. Scott and G. J. Scott

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Anil Thakoor, JPL

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